Interim Report

A Review of the Resources and Facilities Required to Conduct Maintenance of Unmanned Aircraft Systems

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July 2006

Interim report prepared in accord with inter-agency agreement DTFA01-01-X-02045 between Federal Aviation Administration (FAA) Human Factors Research and Engineering Division and National Aeronautics and Space Administration (NASA) Aeronautical Safety and Human Factors.

Introduction

Maintenance error is a significant, but sometimes hidden, factor in aviation accidents and incidents. If unmanned aircraft (UAs) are to operate safely in the National Airspace System (NAS) it will be necessary to understand the unique challenges of maintaining unmanned systems.

This research has been commissioned by the FAA to assist in identifying human factor issues in the maintenance of unmanned aircraft so that it can begin to develop policies, procedures, and approval processes to enable operation of unmanned aircraft in the NAS. Previous reports in this series have provided an introduction to UA maintenance issues and have outlined emerging differences between the maintenance of conventional aircraft and UAs (Hobbs & Herwitz, 2005; Hobbs and Herwitz, 2006a; Hobbs and Herwitz, 2006b).

In this phase of our research, we address the resources required by maintenance facilities and we identify characteristics of typical UA maintenance facilities. The information is this report was collected in two ways. First, a series of interviews was held with subject matter experts. Second, representative UA systems were selected for examination as case studies.

Scope of the research

This report is focused on unmanned aircraft systems where the airborne component weighs less than 500 lbs. We consider that larger unmanned aircraft systems for non-military applications will be maintained by FAA-certified personnel to the same standards as conventional aircraft. The unique challenges of maintaining unmanned systems are likely to be most pronounced among smaller UA systems.

We have defined "resources" as the means that must be available to enable maintenance personnel to perform maintenance tasks. Resources can include (1) buildings or immobile physical structures, (2) moveable equipment and tooling, (3) spare parts and materials and (4) information resources, primarily documents. We have not included knowledge, skills or training in our definition of resources, as these aspects will be dealt with in other stages of this research.

Part 121.367 (b) of the Federal Aviation Regulations states that the holder of an air carrier certificate must ensure that "…adequate facilities and equipment are provided for the proper performance of maintenance, preventative maintenance, and alterations…" Part 145 of the Federal Aviation Regulations provides general information on the facilities that must be possessed for the granting of a repair station certificate. The required resources include: housing for facilities, equipment and materials; appropriate work areas; support equipment; appropriate lighting and ventilation; necessary equipment, tools and materials; and access to current documents and data such as airworthiness directives and manuals.

Diversity of UA systems

A wide variety of UA designs are currently in operation. These range from small hobby-store foam models, to limited-production specialist systems, to mass-produced systems such as those being delivered to the military in large numbers. Many UAs utilize conventional fixed-wing designs, however rotary wing aircraft are also in common use. Lighter-than-air aircraft are showing promise for a variety of unmanned uses. Propulsion systems include: electric motors; two-stroke gasoline; four stroke gasoline; single cylinder gasoline engines; multi cylinder gasoline engines; and small jet turbines.

In most cases, the components used in UAs are not sourced from aircraft industry manufacturers. Commercial-off-the-shelf (COTS) components such as servos are widely used, in many cases manufactured for radio-control hobby purposes. There are several specialized autopilot manufacturers, however, in most cases, standard COTS laptop computers are used to interface with aircraft control and link systems.

Types of maintenance tasks

For the purposes of this research, we defined maintenance as any activity other than flight control tasks, performed on the ground before or after flight to ensure the successful and safe operation of an aerial vehicle. Under this broad definition, maintenance includes assembly, fuelling, pre-flight inspections, repairs, and software updates, but does not include piloting tasks such as flight planning or the input of flight commands. Maintenance activities may involve the vehicle as well as ground-based equipment such as the UAV Ground Control Station (GCS).

Scheduled vs. unscheduled maintenance

Maintenance tasks can be divided into two broad categories: scheduled and unscheduled (Table 1). The distinction between these two categories has significant implications for maintenance human factor. Scheduled maintenance tasks are typically preventative, but include assembly, disassembly, handling and other anticipated tasks that must be performed to ensure the system is prepared for flight. Scheduled tasks tend to be performed regularly and so are usually familiar routines for maintenance personnel. On these tasks, experienced personnel will be unlikely to make mistakes related to a lack of knowledge or skills, but may be involved in maintenance discrepancies related to breakdowns in team work, or everyday “stupid” mistakes such as forgetting to install components, and action slips where a person absent-mindedly performs a routine action that they had not intended to perform (Reason and Hobbs, 2003). .

Unscheduled tasks are usually corrective in nature, and are performed in response to unplanned events such as aircraft damage or component failure. Although some unscheduled tasks are minor, others require extensive system knowledge, problem solving and specialized skills.

Location of maintenance activities

Maintenance tasks can be divided into three further categories depending upon where the work is carried out. Field maintenance is carried out at the flight location. Although conventional aircraft generally operate from airfields with fixed facilities, UAs may be operated in rudimentary locations where few resources are available for field maintenance. Minor workshop tasks are performed at the operator’s facility and would typically require basic workshop tools and equipment. Major workshop tasks on the other hand are likely to require the component in question to be shipped to the manufacturer, or be dealt with by specialized maintenance personnel.

Table 1. Categorization of maintenance tasks, and examples of each type of task

	Scheduled tasks	Unscheduled tasks
Field maintenance	e.g. assembly, fuel mixing, calibration and adjustment	e.g. minor repairs, troubleshooting operational faults
Minor workshop tasks	e.g. preventative maintenance, replacing spark plugs	e.g. minor repairs and alterations
Major workshop tasks	e.g. scheduled engine overhaul	e.g. repair of major damage

Methods

Two methods were used to collect the information contained in this report. The first method consisted of a systematic review of the structured interviews held with 35 UA operators and manufacturers. The interviews are described in an earlier report (Hobbs and Herwitz, 2006a).

The second method involved detailed discussions with two manufacturers and two user groups. The result is a presentation of 4 case studies that represent the diversity of the emerging UA industry. Case example #1 is a small fixed-wing UA; case example #2 is a rotary wing UA; case example #3 is a lighter-than-air radio controlled airship; and case example #4 involved a visit to a military UA testing and maintenance facility. It is important to note that information on scheduled tasks was more readily available than information on unscheduled tasks.

Also included in this report are onsite observations of UA operations and maintenance activities at the "Small UA Fire Demonstration" at Fort Hunter Liggett in California (June 5-7, 2006). Participants at the demonstration featured four leading UA service providers: UAV Collaborative and RnR Products; Insitu Group; AeroVironment; and Intellitech Microsystems.

Interview results

Of the 35 interviewees, 58% were manufacturers involved with more than one UA. Of the interviewees, 90% were focused on fixed wing UAs.

Field maintenance

The Operators of small UAs (which included manufacturers) reported that field maintenance could be performed under a simple canopy or tent structure if no building or hangar was available. Access to a standard hangar was often preferred.

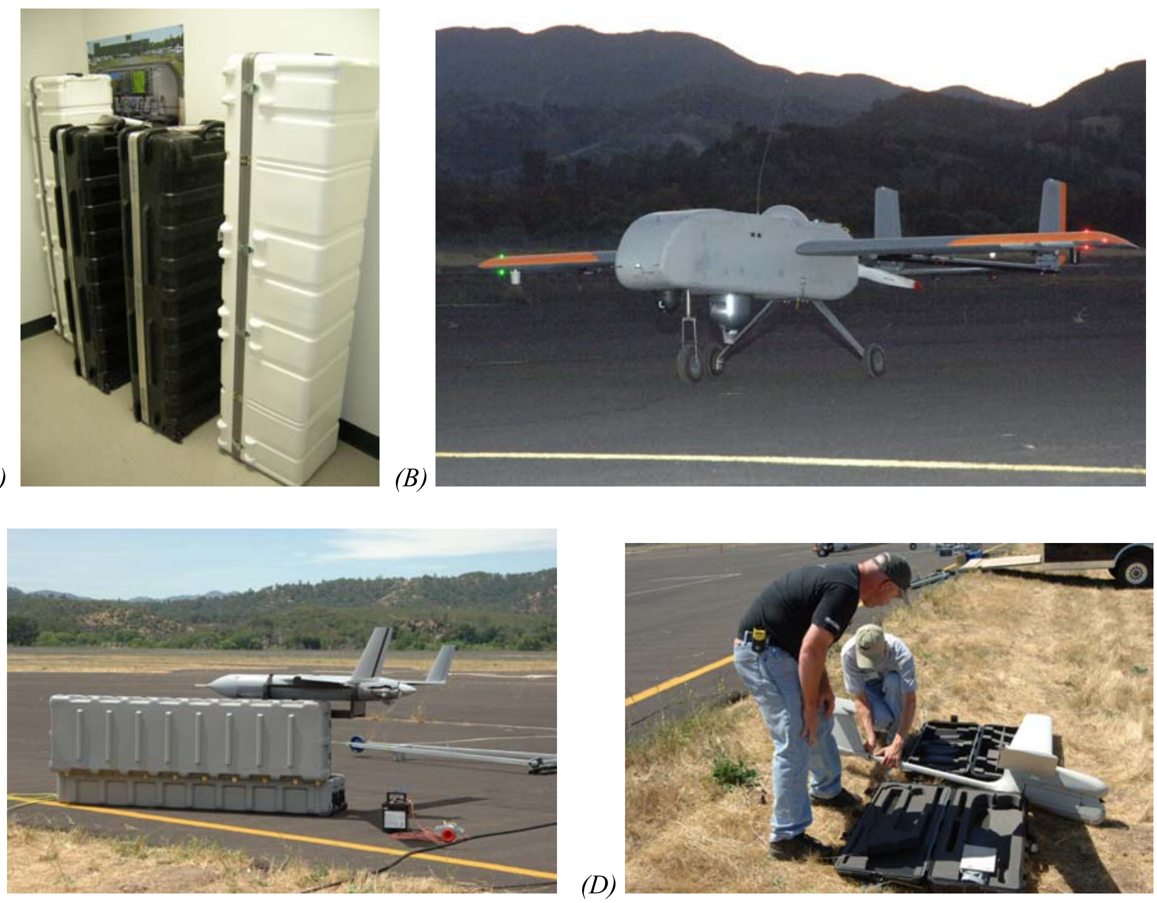
The following tools and equipment were noted as necessary for field maintenance:

- Transport containers
- Equipment to measure deflections of flight surfaces

- Wing stands
- Tools to check torque on servos
- Set of small tools
- Balance device to check center of gravity
- Equipment to charge and discharge batteries
- Spectrum analyzer (not strictly a maintenance tool, but deemed advantageous to check for electromagnetic interference)

In addition to hardware/equipment and tooling, other types of needed resources include software and printed information (e.g., documentation; guidebooks; service bulletins).

Transport was identified as one of the primary maintenance concerns following deployment to flight operational sites. Post-shipment wiring problems (e.g., wiring kinks; detachment of end wires) are not readily discerned by visual inspection. For this reason, particular attention is directed to the packing procedures and the characteristics of the transport containers (Fig. 1).



(A) *(B)* *(C)* *(D)*

Fig. 1. Transport cases for: (A-B) Vector-P UA of IntellTtech Microsystems; (C) Scan Eagle UA of the Insitu Group; and (D) Puma UA of AeroVironment.

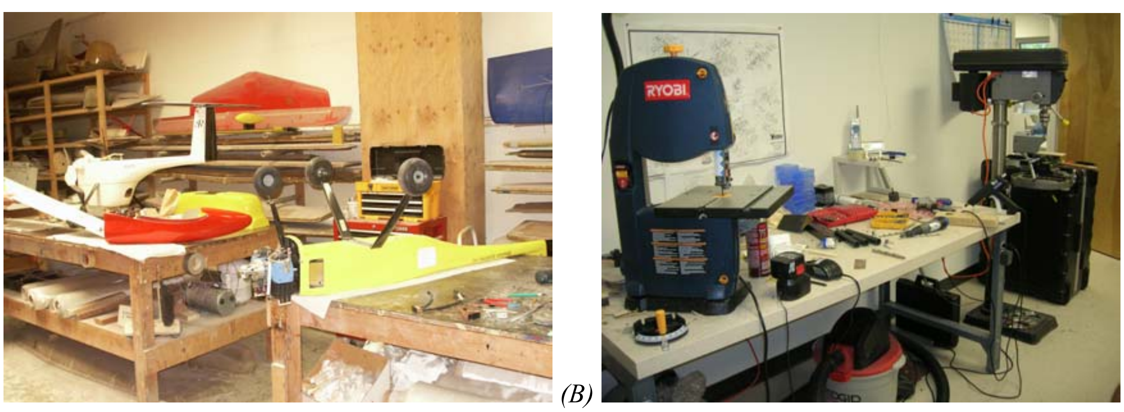
Wing stands and tools to check torque on servos were noted as needed resources by some, but not all, of the interviewees. A balancer was recognized as a requirement for checking the center of gravity. For the lighter-than-air blimp-like UA, a space requirement was identified to enable laying out and filling the blimp with helium. Upon deployment to field demonstration sites, UA providers typically include backup UAs (Fig. 2).


(A) (B) (C)

Fig. 2. Backup UAs for each UA provider participating at the Small UA Fire Demonstration at Fort Hunter Liggett in June 2006: (A) Scan Eagle UAs; (B) Vector-P UAs; and (C) APV-3 UAs,.

Workshop tasks

No maintenance resource or facility was consistently mentioned as necessary, except adequate workshop workspace (Fig. 3).



(A) (B)

(C)

Fig.3. (A) Airframe repair shop for APV-3 UA of RnR Products (Milpitas, CA); and (B) Light machine shop and electronic work station for Vector-P UA (Bowie, MD).

The following facilities and resources were preferred for workshop maintenance:

- Dust free environment
- Light machine shop facilities
- Facilities to charge and discharge batteries correctly
- Oscilloscope
- Soldering station
- Fine drill
- Specialized material for airframe repairs (e.g., composites; carbon fiber; Kevlar; epoxy), although much of this airframe work was sent back to the manufacturer
- HAZMAT facilities if composite materials used
- Internet access for autopilot software upgrades

Qualitative case studies of maintenance facilities

Case example #1: Small fixed wing UA

Tasks undertaken to ensure functionality of a small UA were detailed by RnR Products, Inc., the manufacturer of the widely used APV-3. The APV-3 has a wingspan of 12 feet, a takeoff weight of 60 pounds and a cruise speed of 55 mph. The APV-3 has been approved by the NASA Ames Research Center Airworthiness and Flight Safety Review Board (AFSRB) and flown in the National Airspace System at the San Bernabe Vineyard near King City, CA and at Eagle Field, CA under Certificates of Authorization granted by the Airspace Branch of the FAA Western Pacific Region. The APV-3 has not been required to meet standards of redundancy, testing and documentation applied to larger military UA. It has been flown numerous times at Moffett Field, CA, and completed an 8-hour endurance flight in November 2003. All operations have been over areas of low population density

Preventative Maintenance

Upon delivery or transport of aircraft and associated components to the operational site, the work location for field-based preventative maintenance is outdoors on the launch site's runway.

- Fixed resources: If a mobile vehicle (e.g., van) is used for transport of the airframe, no buildings or sheltered structures are needed (weather permitting).

- Tools and equipment: The toolbox used in the field features Allen wrenches and drivers, and Phillips and basic screwdrivers. Key tools include the Allen driver for wing bolts, the Phillips screwdriver for stabilizer bolts, and a standard slotted screwdriver for the nylon stabilizer. Required equipment includes the refueling system and a voltmeter.

- Spare parts and materials: A second fully equipped aircraft is transported to serve as a backup and as a possible source of spare parts.

Standard Preflight Tasks: Field assembly of the airframe involves checking the electrical wiring linkages (difficult to inspect when housed within the small UA airframes), bolting each wing to the airframe using an Allen wrench, and inspecting the pre-mounted stabilizer positioned on the top of the tail fin. In some cases, the stabilizer is removed for shipment, and two bolts are used to securely mount the stabilizer to the fin. It is important to ensure that the fin was not bumped or moved in transit. Once the two wings are joined and the aircraft has been fueled using the reversible fuel pump, the airframe is ready to fly. The next set of tasks involves preparation of the GCS.

The GCS software "gain settings" must be the same as in previous flights. This task is accomplished by viewing the "gains page" of the Operator Interface on the laptop that has the autopilot system software. It also is necessary to check the limits of maximum and minimum speed and altitude, and the LOL (loss of link) scripted response set in the software package.

The local barometric pressure or elevation is then entered into the Operator Interface. Given the fact that the calibration procedure for defining altitude has error, it would be desirable to have an on-site barometer to obtain barometric pressure.

The next step involves establishing zero pressure by covering the pitot tube projecting out from the wing. To verify that the pitot tube can indeed detect airspeed, it is necessary to blow directly into the pitot tube. An important preventative maintenance task is making sure that there is no kink in the flexible pitot tubing.

The power requirements for the aircraft, the engine starter, and the GCS are met using battery packs. Two 12V Triton chargers are used to charge the battery pack on the aircraft. The engine starter is powered by a pair of 12V batteries. Included is a Miller RC gear reduction starter attached to this 24V power source. For recharging the engine starter batteries, a Diehard car battery is used.

When starting the engine, the compression release knobs must be pressed into the cylinder to open the valves and vent them to ease starting. The valves, then, close and remain sealed for the remainder of flight. Once the compression valves have been opened to start the engine, the engine is run until the propellers are primed and ready to run for airborne flight. The external kill switch must be set to run.

To ensure that the critically important laptop GCS remains powered, a Coleman 400W inverter is used to turn DC power into AC power so that the laptop can be plugged into the AC line. The inverter makes it possible to plug the GCS into the power pack and operate it for 8 hrs. Should the battery fail, this system gives a margin of 2 extra hours of flight time, enabling the UA to return home. The preflight command-and-control checklist is set forth in Table 2.

Standard Postflight Tasks: After each flight the aircraft is visually inspected, with particular attention directed to loose linkages between components. Following a successful flight, the first task involves "post-flight defueling." This task requires the use of a "reversible fuel pump." The volume of fuel drawn from the pump is used to compute the fuel consumption (volume before and volume after flight) in units of fluid ounces per hour of flight. This task is necessary to evaluate engine performance. Other post-flight preventative maintenance tasks include checking battery voltage status using a voltmeter and visual inspection of possible loose linkages

Table 2. Preflight command-and-control checklist for APV-3

1. ☐ Adjust throttle to shut off engine with throttle and throttle trim in full low positions.
2. ☐ Verify throttle fail safe setting by loss of manual radio control link activating return to home mode.
3. ☐ Fail safe setting on auto/manual switch is auto and throttle low
4. ☐ Verify loss of ground control station modem link will activate return to home.
5. ☐ Verify engine shut off commanded by wireless modem
6. ☐ Verify engine shut off on loss of engine shut off modem links
7. ☐ Verify transponder response to queries with transponder test set.
8. ☐ Verify autopilot control of payload power on/off by zoom in/out.
9. ☐ Verify all control surface motion.
10. ☐ Verify manual radio control range with original transmitter antenna and payload transmitting data, use augmented antenna if range with original transmitter antenna is not satisfactory.
11. ☐ Determine payload power consumption.
12. ☐ Verify payload command, telemetry and data transmission.
13. ☐ Determine weight and balance with this payload configuration

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Corrective Maintenance

Workshop and field maintenance: The tasks ensuring the post-flight functionality of the APV-3 are performed both in the field and in the manufacturing workshop.

Two of the more common elements requiring minor corrective maintenance are propeller replacement and wheel replacement. Replacement of these parts has been required as a result of cross winds during landing that caused propeller contact with the runway and tire displacement from the tire rims.

Propeller replacement also may require the installation of a new spinner. During all deployments, an extra spinner is always included in the mission accessories. In the field, an Allen key is used for the screws that connect the perimeter of the spinner to the back plate. A crescent wrench is used to connect the propeller bolt to the dry shaft. A wrench is used for a 1/4-20 nut and spacers. A driver is used for 1/4-20 socket cap screws and for a 1/4-20 bolt that enables attachment to the carbon fiber strut of the airframe.

Case example #2: Rotary wing UA

The U.S. Army's Rmax rotary wing UA is maintained by NASA staff and commercial contractors based at the NASA Ames Research Center at Moffett Field. Personnel at this non-military facility described the resources, necessary facilities, and tools and equipment used for maintenance (Fig. 4). They detailed the typical tasks and where the work is peformed.

(A) (B) (C)

Fig. 4. Rotary wing UA: (A) repair shop; (B) wiring work station; and (C) tool storage cabinets (Moffett Field, CA)

Preventative maintenance

For the U.S. Army's Rmax rotary wing UA, the Yamaha checklist is referenced for all preventative maintenance tasks. Preflight inspections are an important element of preventative maintenance. Annual inspections called out by the manufacturer are performed to remain in conformity with new developments detailed in service bulletins. Time limits on some components are detailed in the Yamaha Maintenance Manual. Rubber components, for example, have a 5-year replacement requirement.

A specialized toolbox was assembled by the U.S. Army maintenance team for the metric tooling required for the Yamaha Rmax. The toolbox includes socket wrenches, screwdrivers, and specialized torque wrenches in units of Newton meters.

The maintenance team follows a rigorous annual inspection procedure comparable to that applied to manned aircraft. This annual inspection involves almost full disassembly of the airframe enabling: (1) assessment of "slop" in the bearings; (2) regreasing specific components; (3) checking torque on specific components; (4) checking operational "smoothness" by watching and operating parts in partially disassembled state; (5) checking the rigging of the rotorblades; (6) measuring travel distances of servos; and (7) using a digital protractor (precalibrated by the U.S. Army) to precisely measure the angles that the rotor blades go through. If there are any serious problems involving components that are "out of tolerance," then the components are shipped back to the manufacturer.

The battery system used for radio communication is equipped with an audio warning if battery power declines to unacceptable levels. The batteries used are COTS nicads. All wiring in the rotary wing UA is standard aircraft milspec wire: fully insulated, durable, and chemical resistant.

Attention is carefully directed to payload weight and balance, ensuring that the Yamaha-defined limits are never exceeded. Weight and balance are checked using a custom-made apparatus. To date, the payloads have not had any effect on the flight control system

If any modifications are made, a ground-based functional check is carefully performed in the hangar. The first stage of the check involves turning on all functional components, with the exception of the engine. A custom-made frequency scanner is used to check all RC frequencies (1 to 90 channels), and make sure that only the Rmax operational frequency is detected. The next stage involves powering the engine and rotor blades, and the aircraft lifts off and is flown a couple of minutes to a flight height of 20-30 feet. The Rmax is initially flown in RC mode. Once a comfort level has been achieved, the aircraft is shifted to autonomous mode for both autonomous landing and takeoff for the demonstration of varied flight plans. The RC pilot is always present to take control in the RC mode should there be an autonomous mode failure.

Corrective maintenance

The U.S. Army maintenance personnel have not been required to conduct corrective maintenance tasks because corrective maintenance was needed only on one occasion. According to the Lead Workshop Technician, the Rmax rotary wing UA has had a high level of reliability that exceeds 90%. The only problem was an engine-quit episode over Moffett Field. The flight data recorder revealed that the engine still had ignition at the time of its failure. Its impact on the ground from a flight height of 50 ft resulted in a fractured and bent airframe, and breakage of the landing gear. The main rotor blades, the tail rotor blades and the payload remained intact. The airframe was sent back to the manufacturer. The manufacturer replaced airframe components, with no effort invested in trying to repair the damaged unit. The broken landing gear assembly was simply "wrenched off" and replaced.

Update bulletins from the manufacturer are viewed as an important aspect of Rmax maintenance. Most notable was an update bulletin that required replacement of what the manufacturer considered "failing" tail rotor blades (despite the fact that this "failing" condition was not noted by the users at Moffett Field).

Water ingress is a potential problem that could lead to system damage and require corrective maintenance. The U.S. Army will not fly the Rmax in rain conditions. Flights are cancelled if rain is in the forecast. The Japanese will fly in light rain, but not heavy rain. The risk of water seepage into unprotected parts is a reality, particularly for the payload. For use over ocean environments, additional protection against salt spray and salt water ingress would be necessary.

<u>Case example #3: Lighter than air UA</u>

AeroStar International is one of the few manufacturer and users of lighter than air UAs willing to discuss human factor issues. In a detailed discussion with AeroStar International, an important distinction was made between two types of UAs that determined resource and facilities needed for maintenance: (1) low-altitude lighter-than-air UAs (<500 ft); and (2) high-altitude lighter-than-air UAs (60,000 to 75,000 ft).

- Fixed resources: no buildings needed; shelter needed under windy conditions for spreading out envelope and evaluating its condition prior to inflating

- Tools and equipment: A standard voltmeter is used to ensure that the battery is at full capacity. A Dwyer magnehelic hand-held pressure gauge is used to verify that full pressure is established in the UA's envelope.

- Spare parts and materials: A complete inventory of spare units is transported to each deployment site. The UA will be operated using primary components. If there is a malfunction of one of the components, backup parts are simply incorporated into the operation.

Low-altitude lighter-than-air UAs: Preventative maintenance

Low-altitude UAs are being used for applications ranging from advertising to surveillance (Fig. 5). For preventative maintenance, all of the components are subject to a preflight operational checkout. The envelope has a diameter of 38 ft. "Standard" remote control (RC) equipment is used for flight control, which is performed all within visual range. Portable trailers are used for equipment transport. The facility requirements are minimal, with the equivalent of a home workshop satisfying their needs. After each flight, there is postflight recharging of batteries and visual inspection of the envelope.

(A)

(B)

Fig. 5. Lighter than air low altitude UAs: (A)-(B)

Low-altitude lighter-than-air UAs: Corrective maintenance

The envelope is made of ripstop nylon heavily urethane film and coatings. The manufacturer offers a service and storage arrangement that would involve post-flight inspection and correction of any anomalies that are detected. Holes do not develop in the envelope unless there is major damage during flight associated with hitting large objects such as trees. The maximum operational airspeed of a lighter than air UA is 15-20 mph. In wind conditions exceeding 10-15 mph, these UAs cannot operate. If there is a loss of RC control, the lighter than UA deflates and floats to the ground. The envelope, thus, serves as a "fail safe" for simple landing.

High-altitude lighter-than-air UAs: Preventative maintenance

Aerostar International offers non-tethered helium-filled blimps for military use. These high altitude lighter than air UAs are capable of operating at altitudes exceeding 60,000 ft. These UAs are flown completely by computer. The key components requiring preflight preventative maintenance include: the propulsion system; the command and control module; the ballast system; and the solar arrays that help sustain the battery power. The envelope, which measures 160 ft in length, is for one-time use only, and it is destroyed and disposed of upon returning to the ground. The other components are often reusable, but are subject to significant refurbishing after flight. The airship designed by AeroStar is for flights of 30 to 45 days in duration.

High-altitude lighter-than-air UAs: Corrective maintenance

Upon landing, the entire system is carefully inspected to evaluate the response of the system to the cold temperatures at high altitude and for possible repairs of the reusable components. Functional tests are performed on the propulsion system, and this requires an engine stand. The electronic components need specialized bench modules for servo checks and for evaluating the ballast system. The overall facility requirement is satisfied either at the manufacturing facility or in a "normal" hangar used for standard aircraft.

<u>Case example #4: An inventory of small and medium fixed-wing UAs</u>

An on-site visit to a leading east coast military aircraft and UA testing and maintenance facility was undertaken to provide a point of contrast with the non-military facilities described in this report. The visit was made to the US Navy's Maritime UA Demonstration and Operations (MUDO) Group at St. Inigoes, MD.

The MUDO technical manger of the UA inventory provided a visual walk-through of the entire facility (Webster Hangar). No photographs were allowed. It was clear, however, that the MUDO Group carefully maintains its pristine, well-inventoried collection of tools and replacement parts. They are equipped with facilities for the creation of their own specialized (often calibrated) tools and components. Webster Hangar has a well trained staff, and working facilities in the standard aircraft hangar that are comfortable and expansive with large open work areas.

Discussion and conclusions

In general, the resources required for field maintenance of UAs comprise basic and readily available tools and equipment. For on-site assembly, wing stands or other support equipment may be needed. Equipment to measure the travel distances of flight control systems also is necessary. Fueling/defueling aircraft and battery charging may require special equipment. Equipment to check the weight and balance of UAs (and the corresponding weight and balance charts) also is needed for some UA types, particularly given that changes to the payload may result in weight and balance changes.

Maintenance documentation and data are among the maintenance resources required according to FAR Part 121.367 (b). The provision of appropriate procedures and documentation for UA maintenance requires further attention from some smaller UA manufacturers. It appears that some scheduled and unscheduled maintenance tasks are performed without comprehensive task documentation, relying largely on the experience of the individual maintainer. Large-scale production and operation of UA systems will require the provision of formal maintenance guidance for field and workshop tasks.

Some UA operators have developed the practice of transporting a second UA to the operations site to be used as a source of spares should unscheduled field maintenance be required. The use of an otherwise airworthy aircraft as a source of spares introduces several human factors challenges. The cannibalization or removal of parts from the donor aircraft must be thoroughly documented. Furthermore, the use of an otherwise flight-ready donor aircraft as a source of spare parts introduces additional opportunities for maintenance error. Not only must the part in question be removed from the donor aircraft and then installed on the recipient aircraft, but steps must then be taken to replace the removed part on the donor aircraft. Maintenance confusion related to parts cannibalization has been a factor in airline maintenance incidents (Hobbs, 1997).

The issue of spectrum management (while not strictly a maintenance issue) is of concern to UA operators. Interference from other spectrum users can present a serious threat to UA operation. Including a spectrum analyzer in the field kit can help to manage, but not eliminate the risk of radio interference.

More specialized resources may be required for workshop maintenance tasks, including facilities for composite repairs, HAZMAT personal protective equipment, and internet access for software updates to autopilot systems.

An important distinction needs to be made between UA manufacturers (small and large businesses) and UA service providers and users that have simply purchased commercial off-the-shelf UA technology. UA service providers inevitably turn to manufacturers when addressing significant maintenance issues. An implication of this situation is that the personnel who perform corrective maintenance at the manufacturer's site will generally require more specialized knowledge, skills, and abilities than personnel who perform scheduled field maintenance.

When considering the types of resources required by unmanned aircraft maintenance facilities, a fundamental distinction needs to be made between small business providers and DOD (e.g., MUDO; Rmax) UA operators. The small business provider may actually supply DOD interests, but they house themselves in their own low budget working environments.

The main focus of UA service providers involves carefully following manufacturer instructions and ensuring that wiring work, which may involve payload components, is intact. The Rmax Group at NASA Ames and MUDO at St. Inigoes as well as the lighter-than-air Aerostar

International, thus, operate quite differently than the IntelliTech Microsystems and RnR Products groups. These smaller commercial entities conduct airframe maintenance in close quarters (e.g., leased office space converted to garage-like workshops; often make-shift workrooms).

The MUDO and Rmax Groups are well staffed and their working facilities are characterized by large open work areas. They carefully maintain their pristine well-inventoried collection of tools and replacement parts. The small business provider, in contrast, has limited resources for the creation of tools and components, and no carved-out storage niches for tools in drawers. Small business must cope with the lack of airframe/hull insurance, while the MUDO and Rmax Groups have no such concerns. In comparison with the small UA service providers/manufacturers (e.g., RnR; IntelliTech) that are just trying to maintain their business, the MUDO Group, like the Rmax Group, clearly follows rigorous well-documented maintenance and inspections schedules.

UA transport from workshops and storage facilities to the field is one of the key issues pertaining to maintenance and human factors. Maintenance, therefore, must focus on the nature of and the care for “transport cases,” which are often homemade or custom-built with little past history that details their performance under rough transport conditions (e.g., vibration on rough roads).

The payload requirements that justify the use of UAs cannot be viewed independently when considering the human factors maintenance issue. It is important to emphasize that UA payloads often exceed the monetary value of the airframe by an order of magnitude. As a result, the payload is the main focus of the maintenance activity. The payload is closely tied to the performance of the airframe, particularly because the payload is often positioned on the exterior. Payload pods are most frequently positioned on the underbelly or on the nose of the airframe. In addition, the communication antennas often project up and/or down from the wingtips. Payload weight and balance, therefore, may have a significant influence on aircraft performance. For this reason, UA payloads require full attention during ground-based maintenance. Payloads also have the potential to interfere with the in-flight performance of the aircraft and maintenance personnel must be prepared to consider the potential airworthiness implications of payload changes.

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